

Can. Pam. *Addison, William L.T.*

ON

Crystal Formation of the
Elements

AND THEIR

Allotropic Modifications

With a Deduction of the Atomic Forms therefrom

..BY..

WM. L. T. ADDISON, B.A., M.B.

TORONTO:
THE MAIL JOB PRINTING CO'Y, LIMITED.
1898.

CAN
PAM
ADDISON, WM. L.T.

Dr Robert Bell
with the author's compliments

ON

Crystal Formation of the Elements

AND THEIR

Allotropic Modifications

With a Deduction of the Atomic Forms therefrom

..BY..

WM. L. T. ADDISON, B.A., M.B.

TORONTO:
THE MAIL JOB PRINTING CO'Y, LIMITED.
1898.



PREFACE.

An outline of the research of which this monogram treats was given before Section B of the Toronto meeting of the British Association for the Advancement of Science.

The paper after all possible condensation proved too long for the time allotted to its reading. Its length and character renders it inconvenient as a scientific magazine article.

In response to a number of requests that the paper be published, the Author, after revising the MS. and adding where he deemed it advisable, issues the paper in its present form.

WM. L. T. ADDISON.

April 27, 1898,
BYNG INLET P.O.
ONTARIO, CANADA.

CHAPTER I. Molecular form and arrangement.

CHAPTER II. The form of the atoms of the elements of group IV. of Mendeljeff's table.

CHAPTER III. The forms of the atoms of the elements of group V. of Mendeljeff's table.

CHAPTER IV. The atom forms of the elements of group VI. of Mendeljeff's table.

CHAPTER V. The atom form of iodine, and the phenomena of crystallization of iodine from solutions.

CHAPTER VI. The atom forms of the elements of groups III., II. and I. of Mendeljeff's table, and the influence of atomic form upon malleability.

CHAPTER I.

Molecular Form and Arrangement.

As a preface to the research presented before you, a short outline of the history of the progress of the study of Crystals, is interesting.

Nicolas Steno, a Dane, in 1669, gives, as a result of his observations of crystals, the law, "*in plano axis laterum et numerum et longitudinem varie mutari non mutatis angulae.*"

In 1707 Robert Boyle observed bismuth to crystallize from its molten state. In 1768 Linnaeus classified crystals as cubes, prisms, and pyramids.

In 1772, Bergman drew attention to the planes of cleavage in the rhombohedron of calcite, and made a study of cleavage, internal forms, and arrangements of crystals.

In 1783, Romé Delisle formulated his law of constant angles, that the angles formed by corresponding faces of crystals of the same compound are equal. This law under more modern knowledge has been modified to the following: "the angles formed by corresponding faces of crystals of the same compound are under the same temperature equal." Following and as a later contemporary of Romé Delisle lived Hany. From observation of the planes of cleavage of calcite, Hany built the following theory of the structure of crystals:—"In each mineral there exists integrant molecules, solid bodies incapable of further division and of invariable form, with faces parallel to the natural joints indicated by mechanical division of the crystals, and with angles and dimensions given by calculation and observation combined. These molecules are marked in different species, by distinct and determinate forms, except in a few regular bodies as the cube, which do not admit of variations. From these integrant or primitive molecules, all the crystals found in each species are built up according to definite laws and thus secondary crystals are produced." Of these primitive forms six only were known from observation, the parallelopiped, the octahedron, the tetrahedron, the hexagonal prism, the dodecahedron of triangular faces and composed of two six-sided pyramids base to base, and the rhombic dodecahedron. In order to produce secondary crystals which cover the primitive form, so as to disguise it in so many different ways, he supposed the enveloping matter, "to be made up of a series of laminae, each decreasing equally in extent either in all directions, or at certain points. This decrease takes place by the regular subtraction of one or several ranges of integrant molecules in each successive layer, and the theory (determined by calculation of the number of these

ranges), can represent all known results of crystallization, and even anticipate discoveries, discover hypothetical forms, which may some day reward the research of the naturalist."

He also discovered the modification of the angles, edges and faces according to the laws of symmetry: and, that the variations of form in apparently similar compounds, indicate in reality, a difference in the composition.

Later Mitscherlich discovered the replacement of one compound in a crystal, by other compounds of similar chemical grouping. This he discussed as vicarious displacement.

If the experiment of fracture of calc or Iceland spar be followed, the inference is of a fission into integrant molecules, and that these molecules are definitely and regularly arranged, which arrangement accounts for its gross form. If the calc-spar be ground, and the particles (which microscopically are rhombohedra) be placed in mechanical contact, the result is not a gross rhombohedron such as has been destroyed, but still a powder. At some time in its history, there has been some agency, not now present, at work to cause this arrangement. If, however, some crystals of potassium ferrocyanide (which show an equally marked cleavage) be crushed, as was the calc-spar, and placed in water, a new condition is brought about. The powder is dissolved, and the result is a yellow solution.

If the water be evaporated from this solution, there are left crystals of similar angles to those destroyed by grinding, showing that though the connection of some parts of the crystal have been severed, yet it has within itself, a selective power for some particular and chosen arrangement. The molecules have been set quite free in the solution, and have been given the opportunity of selection, as determined by some power within themselves. Were there no attraction the one molecule for the other, as the solution became overloaded the particles would drop down, one by one, to form an amorphous powder. The particles or molecules are, however, thrown out as aggregates of crystals of definite proportions and angles, and of the same angles and proportions as those of the crystal destroyed. *This shows an attraction of some sort, in definite directions.*

The form might arise as suggested by Hany, "from integrant molecules, solid bodies incapable of further division, and of invariable form, with faces parallel to the natural joints indicated by the mechanical division of the crystal, and with angles and dimensions, given by calculation and observation, or both combined"; or from such forms, as are suggested by Dalton's diagrams, roundish or irregular atoms but of indefinite form; or from definite masses, projected in definite directions, to a definite extent in space, so that if these points be joined, they would, in outline, enclose a definite space of a definite form, such as are found in crystals. The gross or resultant form need not be the same as the integrant form, but is a result of the arrangement of such forms.

Hany's theory is an ingenious one, but one founded before the establishing of Dalton's atomic theory, and before the discovery of the dimorphic forms of calcium carbonate.

Such a theory would require two sorts of integrant molecules of calcium carbonate, one for calcite, and one for aragonite.

The regular and rhombohedral forms of carbon and phosphorous would thus require different integrant forms of the same element. Were this theory correct, it would require a plastic atom or molecule, and one in which the form of lighter specific gravity occupies more space than the one of heavier specific gravity. This controverts his theory of invariable molecules.

Were his theory applied to the molecules of compounds, it involves a molecule of faces, which again necessitates either:—(1) a fusion of the atoms within a molecule to form a homogeneous mass of geometric form, or (2) within this geometric molecule a definite space filled by each atom, be this as a whole face, a portion of any or several faces, or be it within the space enclosed by these faces.

The individuality of the form of the atoms within a compound, and their varied arrangements, account too fully and distinctly, for isomeric compounds and stereo forms of the same compound, to accept the first alternative.

Potassium iodide exists in cube form, and by Hany's theory its molecules are cubical in form.

Potassium as an element exists in quadratic octahedra, iodine as an element exists in rhombic plates. Neither of these may make a cubical face by arrangements of their own forms, or by any combination of their face forms, so that the second alternative cannot be accepted.

Dalton's diagrams show the atoms as round forms of matter, attached to each other.

His hypothetical forms do not indicate any special areas of valence, and in them it is supposed that an atom might be attached to another at any part. An arrangement of similar atoms would thus be as shot in a pile, and result in regular forms only, and could not account for such allotropic modifications, as those of carbon and phosphorous, so we must dispense with this theory.

Were a number of atoms grouped about another (as they are), it would produce a grouping of prominences about the central atom. These outlying points give the molecule its form, and such form must determine the gross form. The form of the same compound is constant, and so it follows, that the grouping of the atoms about the central atom, is constant and fixed.

It is found that analogous compounds crystallize in similar forms, often replacing each other in the same crystal, and in so doing modify the crystal but slightly by their presence. Mitscherlich, the observer of this phenomenon, says "substances which are analogous chemical compounds have the

same crystalline form and replace each other." Thus crystallizing in rhombohedra may be found.

CALC. SPAR.	DOLOMITE.	MAGNES. CARB.	MANG. CARB.	FERROUS CARB.	ZINC CARB.
105° 5'	106° 15'	107° 29'	109° 51'	107° 0'	107° 40'

These might better be spoken of as similar forms, for while their angles approximate each other, they all vary slightly.

Their close approximation of form, together with their analogous chemical composition, and the tendency for the one to replace the other in well-defined crystals, show a marked similarity of gross and molecular form.

There is in each a common factor, the group CO_3 , which may be credited as the basis of the common form. The valence of CO_3 being common, there must be a similar placing of the valence areas of calcium, magnesium, manganese, iron and zinc. There must also be some difference in each element, which shall increase the molecule of the compound in a definite direction, and so vary the form resulting from the arrangement of these outlying points in space. This difference must be in the displacement, arising from the difference of size and form of the atoms of the above-named basic elements.

Calcium carbonate occurs as calcite in rhombohedral forms of spec. gr. 2.9, and aragonite in rhombic forms of spec. gr. 2.7. Aragonite if heated breaks down to a powder, which under the microscope is seen to be of small rhombohedra, and is of spec. gr. 2.9, or in other words, breaks down to calcite. This must result from a different arrangement in the two forms of a common sort of molecule. In aragonite the molecule occupies more space than in calcite, and hence, in aragonite at least, there must be some unfilled space between the molecules. So far the substances dealt with have been principally compounds, and so are more complicated. The next chapter will deal with the less complicated substances or elements.

CHAPTER II.

The Above Forms the Elements of Group IV. of Mendeljeff's Table.

Carbon, as an element, occurs in two crystalline modifications, diamond and graphite.

As the diamond it crystallizes in regular tetrahedra, octahedra, rhombic dodecahedra, and trisoctahedra. Its spec. gr. is 3.5 to 3.55, see Von Buchka's tables; or 3.5 to 3.6, see Zirkel's "Mineralogie."

That its cleavage is in regular octahedra, shows a tendency to that form, and that the atoms are arranged in series giving rise to fission in the octahedral planes. It might mean that the atoms are of octahedral form, and it means that the lines of union of the atoms lie in octahedral planes.

If six regular octahedra be placed edge to edge, with a solid angle of each about the same point, a larger octahedron will be obtained. These octahedra do not fill space, but are separated by regular tetrahedral spaces. Suppose regular tetrahedra be placed in these spaces, and the regular octahedra withdrawn, the lines of union and cleavage will still remain the same, that is of regular octahedral cleavage. One of these two forms is necessary to produce such a cleavage. It has been seen, that the form of the molecules is dependent upon the outlying points, and these are caused by the atoms attached to the central atom. The form of these molecules are, therefore, due to the attachments of the atoms, or to the areas of valence of the central atom to which the outer atoms are attached. Such a relationship would show valence, and the form of the atom, or its differentiated and attractive portions, to be intimately connected. If the solid angles of the two solid forms, which would account for the diamond, were areas of valence, then the octahedron would be hexavalent, and the tetrahedron tetravalent. Were the attraction of valence and of crystallization the same, then on the above supposition, the tetrahedra would fulfill the requirements.

So far the atoms have been discussed as solid bodies. Of this there is no proof, yet in the discussion of the hypothesis of atomic forms, a solid, for convenience in nomenclature, will be assumed.

If eight tetrahedra about a point, be attached by their edges, they will give a form with eight exposed surfaces, which if produced would give an octahedron. If eight tetrahedra be attached by their edges, and so arranged as to enclose an octahedron, they will give rise to a form, corresponding in its outlying angles to a cube. If either of these forms be cut through one of its principal axes, it would be divided at the line of attachment, and if each half be reversed and reattached, the form resulting would be found to be the other one of the two forms just described. If the number of tetrahedra attached edge to edge be increased, then the gross form is merely one of fission.

If an addition of regular tetrahedra be made about the octahedral-faced form, until there be thirty-two, about this model by fission, or by building out certain series may be produced, the regular tetrahedron, cube, octahedron, and rhombic dodecahedron. Assuming the octahedral form as demonstrated by fission, on each face is seen a series of three points projecting into space, the satisfaction of which tends toward the trisoctahedral form. In the model of 32 tetrahedra, all the outlying points lie in a sphere, the full satisfaction of which would tend to a sphere and so the curved faces of diamond

crystals. Were the octahedral spaces filled in by octahedra and the tetrahedra withdrawn, there would then be no tendency to the trisectahedral form. Thus the evidence is in favor of the atomic form of carbon being tetrahedral, and of the same number of solid angles as it has areas of valence.

A regular tetrahedron is a four-sided figure, and as such, is the simplest isometric form that may enclose space. If two regular tetrahedra be placed base to base, they give a bipyramidal hexahedron, and one with five solid angles. The sides are of equilateral triangles, and the angles over the combined bases or the zonal edges of the hexahedron are $141^{\circ} 3' 18''$. The angles over the remaining edges are $70^{\circ} 31' 47''$. The solid angles are of two sorts, two apical and three zonal.

This form is of interest, in that it is referred to in the discussion of phosphorus. If an infinite number of regular tetrahedra were arranged edge to edge to give octahedral spaces, the different proportion of the outer layers might be ignored. The inner portion of the model would have a homogeneous arrangement. It is found that in it the tetrahedral faces form the faces of the octahedral spaces, so that for each octahedral face there is a tetrahedral face. The proportion of the tetrahedra to octahedra then, is inversely to the number of their faces or as four to eight or one to two. It may be well while the proportions are fresh in mind to work out some calculations, which will be of use in further study. The space of the regular tetrahedron may be found as follows:

The octahedron consists of two pyramids base to base. The area of a pyramid = $\frac{1}{3}$ the area of its base $\times$ its height. If the model be two inches of an edge, the one-half octahedron is a pyramid of two inches square at the base and $\frac{1}{2}$ the diagonal of the base in height or $\sqrt{2}$.

Thus the area of the octahedron = twice the area of the pyramid = $2 \left(\frac{2^2}{3} \times \sqrt{2} \right) = \frac{8\sqrt{2}}{3} = 3.7712$ cubic inches.

An octahedron four inches in edge would be composed of six octahedra and eight tetrahedra of two inches edge. The area would then be $2 \left(\frac{4^2}{3} \times \frac{2\sqrt{2}}{1} \right) = \frac{64\sqrt{2}}{3}$. The six octahedra of two inches edge would be $6 \left(\frac{8\sqrt{2}}{3} \right) = \frac{48\sqrt{2}}{3}$, therefore the remaining eight tetrahedra would occupy $\left(\frac{64\sqrt{2}}{3} - \frac{48\sqrt{2}}{3} \right) = \frac{16\sqrt{2}}{3}$, and one tetrahedron would be $\frac{2\sqrt{2}}{3}$, or $\frac{1}{4}$ of that of an octahedron. The octahedron of two-inch side has an area of 3.7712 cubic inches, therefore the tetrahedron of two-inch edge has an area of .9428 cubic inches.

In the diamond model the tetrahedra are to the octahedra, as two to one, and the space filled, is as two to four, or one-third the entire space filled.

The length of the bipyramidal hexahedron, as described, may be estimated as follows:—If the angles at the base of a regular tetrahedron be bisected, and the bisecting lines be produced, they will be at right angles to and bisect the opposite sides, and will intersect at the centre of the base, to divide the base into six equal triangles. The angles about the common point

of intersection are 60° each, and the half of the bisected angle is 30° , so that each triangle is half of an equilateral triangle of sides equal to the lines from the centre of the base to the angle. The line from the centre of the base to the edge of the base is one-half that from the centre to the angle of the base. The remaining side is one inch, or one-half the edge of the base. Let the line from the centre of the base to its angle = x , then $[(1)^2 + (\frac{1}{2}x)^2 = (x)^2] = (1 + \frac{1}{4}x^2 = x^2) = (1 = \frac{3}{4}x^2)$, + $(x^2 = \frac{4}{3})$ and $x = \sqrt{\frac{4}{3}} = \frac{2}{\sqrt{3}}$.

Let the line from the apex of the tetrahedron to this centre of the base = y .

The line from the centre of the base of the tetrahedron, to the apex of the tetrahedron, is at right angles to the base, so that in the right-angled triangle of the line from the apex of the tetrahedron to the centre of the base, the line from the centre to the angle of the base, and the edge joining these two lines, the sides are respectively y , $\frac{2}{\sqrt{3}}$, and 2. Therefore $y^2 + (\frac{2}{\sqrt{3}})^2 = 4$, or $y^2 + \frac{4}{3} = 4$ or $y^2 = \frac{8}{3}$ and $y = \frac{2\sqrt{2}}{\sqrt{3}} = 1.63$ inches.

Twice the line from the apex to the centre of the base = the length of a hexahedron of 2 inches edge = 3.26 inches.

If instead of sectioning the octahedral-faced group of eight regular tetrahedra in the principal axes, it be sectioned in one of the diagonal axes of symmetry, the arrangement will then be in layers, which, if produced, are of triangular and hexagonal arrangement. Each layer is composed of two series, one of which has the apices of its tetrahedra pointing downwards, and the other with the apices of its tetrahedra pointing upwards. Such a series has its outer surfaces in a symmetric condition, in that they each are of the same sort, and would tend to equal development on each side. Suppose one of these series to be removed, then that symmetry is removed, and the free areas of attraction are all upon one side, and tend to develop on that side only. Since the apex does not lie over the edge of the tetrahedron, there is a recession from the edge of the base, at the angle of that edge or $70^\circ 31' 47''$, and the result would be a hexagonal column receding from its base at angles of $70^\circ 31' 47''$. Were the base, as it might be rhombic, then the column arising from it would form a rhombohedron. Such an arrangement of tetrahedra would give rise to a rhombohedral form, or a hexagonal form, the long axis of which was oblique to the three zonal axes. This last form might be classified as a monoclinic form, the long axis being oblique, and the three zonal axes be reduced to the rhombic two axes at right angles. Such a form will prove of use in the study of carbon as graphite. Such a form has half the number of atoms to the space as the diamond form has, and so would be of half the specific gravity of the diamond.

Carbon as graphite occurs in the hexagonal and rhombohedral forms. It has a basal cleavage, and the base shows triangular striations. It is a soft, flexible mineral, and in its pure state has a smooth frictionless feeling.

For form see Dana's Text-book of Mineralogy, p. 230.

Von Buchka's Tables, p. 12.

Zirkel's Mineralogie, p. 301.

Concerning the data of graphite many difficulties arise. It is usually very impure, containing quartz, iron, calcium carbonate, etc., with a specific gravity varying from 2.26 to 1.8018. This last figure is from an observation by Lowe, and is given as of a perfectly pure preparation (*des ganz reinen preparirten*), and as such should be accepted as the most nearly correct estimation. The softness, together with the impurity, would naturally bring about a variation of angles, and this does occur. The effect of a soft, pliable character in the crystal form of an element is well shown by potassium, sodium and gallium, all of which crystallize in long, regular and short octahedra. In such crystals the law of constant angles does not hold.

Clark, Suckow and Nordenskiöld found crystals of graphite to occur in the monoclinic system, in which the angle of the base on the oblique axis is $71^{\circ} 16'$ and the angle of the faces as $P. 122^{\circ} 24'$, which angles approximate very closely $70^{\circ} 31' 47''$ and 120 , the angles shown for arrangement of tetrahedra, as described on page 11.

Graphite has been observed by equally accurate observers to be in the hexagonal system. Were this not so the variations to which its angles are subject, together with the close approximation of the observed angles to those of the theoretic form, and the intermobility of the theoretic form, would make it proper to still regard it as hexagonal in form.

In addition to its form being accounted for, its specific gravity is accounted for by the theory of a regular tetrahedral primal form, in that the specific gravity of the diamond is 3.5 to 3.6 and that of pure graphite is 1.8018. Its pliability is accounted for by its extreme opportunity of intermobility, and the triangular striations on the base, may be accounted for by the prominent unsupplied angles of the tetrahedra which are exposed upon the base, and that certain series of these atoms are built up above the others.

Suppose a series of six regular tetrahedra be placed about a point with their bases in the same plane, and with the body of every other one placed respectively above and below this plane, the result will be six hypothetical carbon atoms, each bound to the others with three of its bonds of valence, and in union with all the others, though specially bound to the two more adjacent ones. Thus a ring with free bonds of valence so that 1, 3 and 5 and 2, 4 and 6 are similarly arranged to the base, and with 1 to 4, 2 to 5 and 3 to 6 in symmetric positions towards the centre, is formed.

This arrangement, and this alone, accounts for the peculiarities of the benzene ring. and were this the only proof of the regular tetrahedral form of the atom of carbon, the hypothesis might be regarded as a working one.

Assuming valence to be a function of form, it follows that the remaining elements must have their valence accounted for by their form, and *vice versa*.

A tetrahedral form must be assumed for all the elements of group IV. of Mendeljeff's table, and by its arrangements account for its gross form and physical properties.

Silicon, germanium, lead and thorium all occur in regular octahedra, and may be accounted for as in carbon. There remain unaccounted for titanium, zirconium, tin and cerium. The gross forms of titanium and cerium are not yet known. Zirconium has been observed in microscopic monoclinic leaflets, that is in leaflets of a less symmetry than orthorhombic. Were the other axis known it might be found oblique. Tin was observed by Frankenheim to be in the regular system, but later observers have found it in quadratic octahedra. These quadratic octahedra may be formed of quadratic tetrahedra, whose faces are of equal isosceles triangles.

A section through the oblique lines of symmetry of these octahedral groups, would give series which appear monoclinic. These series would account for the monoclinic leaflets of zirconium. It may be, however, due to a laying of the quadratic tetrahedra down, as in the regular tetrahedra to form a rhombohedron, and that zirconium may be capable of allotropic modifications. Titanium, tin and zirconium dioxides, are not only in the same form, but are isomorphous; showing that the one molecule is of such a form as to replace a molecule of the other compound, in the same crystal, that is of the same form. The oxygen is common to both, hence the atoms of which the oxides are compounds are of the same form. This would confirm the view that the atoms of zirconium are of a quadratic tetrahedral form.

CHAPTER III.

The Atom Forms of the Elements of Group V. of Mendeljeff's Table.

In pursuance of the hypothesis of form being coincident with the function of valence, the atoms of group V. must have a form of five solid angles, and the gross forms must be such as arise from this atomic form.

The specific gravity must be inversely in proportion to the space occupied per atom.

Phosphorous is found in a rhombohedral form of specific gravity 2.34, and in a regular octahedral and rhombic dodecahedral form of specific gravity 1.957 or 1.826 to 2.098. See Von Buchka's tables.

Arsenic and antimony are also found in rhombohedra, and in the regular forms. (See Zirkel's Mineralogie.) There has not as yet been discovered

a regular form of bismuth. Bismuth exists in the rhombohedral form, as does phosphorous, arsenic, and antimony, and is isomorphous with arsenic and antimony.

That there is a regular form in phosphorous is a very significant fact, and tends to show that its primal form is of a regular form, or a combination of regular forms. This is merely a guiding fact.

In carbon there is a rhombohedral form and a regular form, the specific gravities being as one to two. In phosphorous there are rhombohedral and regular forms, of specific gravities three to two. This shows a different arrangement, and arrangement being consequent on form, would tend to show a difference of form.

The bipyramidal hexahedron as described on page 10, has five solid angles, two apical and three zonal, and as such would satisfy our hypothesis, and would at the same time have some features of the regular system.

If these hexahedra be arranged edge to edge, so that about a point two apical and three zonal solid angles meet in such a way that the apical angles are opposite, and the zonal ones arranged symmetrically about the point of union, the arrangement if continued will have its lines of fission and series, in rhombohedral planes, and each series will interlock with the ones above and below it. Thus any series will be incomplete, and will tend to irregular development, and this is well marked in both antimony and bismuth.

The arrangement as described, consists of a series of columns of atoms separated by columns of unfilled space. These columns of space are of unfilled octahedral spaces face to face. Two of the faces of octahedral spaces are in apposition with other octahedral spaces, and thus each octahedral space has six remaining sides, which are in apposition with the faces of the hexahedra. Each hexahedron has six faces, and so the hexahedra and the octahedral are as one to one, or there are two tetrahedra to one octahedron, and one-third of the space filled, or each hexahedron of two inch edge occupies 5.6562 cubic inches of space.

Suppose eight hexahedra to be arranged edge to edge, so that eight apical angles are about the same point, the arrangement of the inner half of these atoms is the same as that of the carbon atoms in the diamond model, and the whole form may be regarded as the octahedral form, made by eight regular tetrahedral atoms with eight other tetrahedra upon the faces, the outlying solid angles of which if joined would form the edges of a cube. The question arises do these groups act as a unit, or do the individual atoms go on adding themselves to the form already within the group?

If one outlying solid angle be built about by individual atoms, the others must be built about to retain the symmetry. To do this it is necessary either to have an apical solid angle in apposition with a zonal one, or to have the atoms reverting into the model, and into an insufficient space.

The arrangement of apical and zonal angles together is a rhombohedral arrangement, and so the atoms do not act in this form separately, but in groups.

In connection with the hypothesis of an eight atom group, it may be observed that there is a potential line of fission in the principal axes of the cube form. The cubical arrangement results in eight apical angles meeting at the same point, and the distance between the two apical angles of the atom is the distance from the centre of the cube to its angle. This has been shown to be in a two-inch edge hexahedron 3.26 inches. The line from the centre to the angle of the cube is one-half the line joining the opposite angles of the cube. If x = the side of the cube, then the diagonal mentioned = $x\sqrt{3}$, and the line from the centre to the angle of the cube = $\frac{x\sqrt{3}}{2} = 3.26$ inches; $x = \frac{6.52}{\sqrt{3}}$; x^3 = contents of cube = $(\frac{6.52}{\sqrt{3}})^3 = 53.341$ cubic inches.

Eight hexahedra occupy 53.341 cubic inches; one hexahedra occupies 6.668.

The specific gravity of the rhombohedral form is 2.34, and since the specific gravity is inversely to the space occupied per atom, the specific gravity of the regular form should be $\frac{2.34 \times 5.6568}{6.668} = 1.985$.

The average of the extreme estimations at the ordinary temperatures as given in Von Buchka's tables is $\frac{1.826 + 2.089}{2} = 1.957$.

Thus the proportions as supposed for the atom form of phosphorous may be regarded as proven.

The specific gravities of the regular forms of arsenic and antimony are not known, so that the proportions of the atoms of these elements may not be proven by specific gravities. They are not, however, of the regular hexahedral form as described for phosphorous, for the angle R would in that case be $82^\circ 18'$. The increasing angle and difficulty of formation of the regular form all would show a change of form. Phosphorous has proportions according to specific gravity of

Angle R $82^\circ 18'$.

" R $85^\circ 4'$, arsenic by observation.

" R $87^\circ 6' 50''$, antimony by observation.

" R $87^\circ 40'$, bismuth by observation.

Suppose about a cube are arranged cubes, one to each face, then each added cube will be towards the centre cube, a projection into space in the directions of the solid angles of a regular octahedron.

The undeveloped spaces between these outlying cubes if represented by a face would give a rhombic dodecahedron.

The atom form has two sorts of solid angles, the apical and the zonal. The most stable crystal form is one in which the different sorts of angles meet each other, about a point in the proportion in which they exist in an atom form. That the form in which different angles meet is more stable than the form in which like angles meet, is a most significant circumstance.

The valence of phosphorous towards oxygen, sulphur and chlorine, is five, toward hydrogen three. All the angles are available to oxygen, and but three to hydrogen. Hydrogen is an electro-positive element of valence one, and the element attracting it, is electro-negative to hydrogen. The two remaining angles or areas of valence are of a sort which do not attract hydrogen, and hence of the same electro condition as hydrogen.

Thus there are angles three of a sort and two of a sort in form, and three of a sort and two of a sort in an electro condition, and an arrangement in which three of a sort are in junction with two of a sort in form, is more stable of equilibrium than an arrangement in which the three of a sort are grouped with three of a sort, and two with two of a sort in form. Is it not a fair inference that the three of a sort in form are the three of a sort of electric function, and the two of a sort of form are the two of a sort of electric function, or that the zonal angles are electro-negative and the apical electro-positive, and that the angle nearer the centre is electro-negative to the more distant solid angle of the atom? In carbon all being equally near the centre, there would be a tendency to all points being supplied, or none supplied by hydrogen. Thus there would be a hydride CH_4 but none of the formulas CH_3 , CH_2 or CH . Of the crystal forms of nitrogen, vanadium, niobium, and tantalum nothing is known.

CHAPTER IV.

The Atom Forms of the Elements of Group VI. of Mendeljeff's Table.

In the study of the elements of group VI. of Mendeljeff's table, it is well to review the two preceding groups. The atom forms of group IV. whether of the regular or the tetragonal systems, have their solid angles equidistant from the centre of the atom.

In group V. the solid angles of the atom forms might be equidistant from the centre, but are in phosphorous, of two sorts which are at different distances from the centre of the atom. The elements of this group as they increase in atomic weight have the solid angles of their atom forms more nearly equidistant to the atom centre.

In group VI. there is a valence of six, and this permits of three sorts of areas of valence, of two each. There may be three axes, and these may be all equal, two equal, or none equal. These may be all at right angles, two at right angles or none at right angles.

Of the elements of this group, sulphur is most known. It occurs in two crystalline forms, a rhombic or the most common form, and a monoclinic, which is obtained by special conditions, and which reverts at ordinary temperatures with evolution of heat to the more stable or rhombic form.

The rhombic form is that found in nature, that deposited from solutions at ordinary temperatures, that from the molten condition at or below 90°C and is of specific gravity 2.05.

To obtain the monoclinic form of sulphur, some sulphur is fused in an earthen crucible, permitted to cool until it begins to crust over, then the crucible is broken, the fluid sulphur drained off, and a network of brilliant yellow crystals left. These if examined within an hour, and while they retain their brilliancy, show a marked and constant cleavage in different crystals, so that the base is at 79° to the long axis of the column. The cross section or basal face has angles 118° and 62° , a condition which might once in a great number of cases have a rhombic proportion but does not tend to assume proportions which when apparently complete are rhombic. The forms are columnar and most frequently ending abruptly. By beating a solution of sulphur in carbon disulphide to 100°C under pressure, the monoclinic form is given. Its specific gravity is 1.96.

This form, as has been stated, reverts in a few hours to the rhombic variety, showing a rhombic cleavage and specific gravity.

This action takes place with the evolution of heat, thus indicating that the rhombic form is the most stable one, and the monoclinic modification is in a condition of strain.

Of whatever primal form the sulphur atom is, it must be of such a sort that it will give rise to, 1st, a gross rhombic form which is stable; 2nd, a gross monoclinic form which is in a condition of strain, and which tends to give a rhombic form when this strain is effective; 3rd, a slight change of specific gravity in the transition, so that this change is inversely to the space occupied per atom; 4th, an arrangement in which there is a free space through which the atoms may rotate in their change from the monoclinic form to the rhombic form.

If six octahedra be arranged about a point with their similar edges together, they will reproduce their own proportions. Sulphur occurs in rhombic octahedra of axes 1, 1.23 and 2.34, so that its atomic form is of these proportions. If a form be built with its shortest axis 8 inches, the remaining axes will be 9.84, and 8.752 inches, and the edges of the primal form will be $12\frac{4.48}{10}$, $20\frac{9.192}{10}$, and $21\frac{8.32}{10}$ inches. The edges of the face therefore are unequal. The two long edges, however, are very nearly of the same length.

In the octahedral grouping, or that edge to edge, the same sort of angles are diametrically opposite, and six meet about a point. If the octahedra were placed face to face, so that similar edges were together, the two apical angles are not opposite, but adjacent; they, however, have an open space above and below, through which they might rotate. The zonal solid angles are arranged in such a way, that the diametrically opposite angles are of different sorts, and the angle above and below the line of union in the same series, are of the same sort, but differ from the angles of the series in approximation.

A rotation to adopt the rhombic arrangement has no space facilities, and requires a great molecular disarrangement to accomplish such a change.

If the model lie upon its face the zonal plane leans to one side, thus — If another model be placed upon this model in the way described above, the lean of the underlying model is corrected, and the base of the column is at right angles to the columnar axis. The base is made up of a series with two axes, a short and a long, which are oblique to one another. The columnar axis is at right angles to both the basal axes.

The unfilled spaces in the octahedral arrangement are of single tetrahedra of the same edges as those upon the octahedra.

In this arrangement the unfilled spaces are in pairs of tetrahedra of the same proportion, as in the octahedral arrangement, and are in the same proportion of single tetrahedra as in the octahedral arrangement, and the octahedra in the monoclinic arrangement occupy the same space per atom as in the octahedral arrangement.

The arrangement may be spoken of as a monoclinic one of the first sort.

It is, however, an impossible one for sulphur in that it does not account for the monoclinic column with an oblique base, its space per atom and so specific gravity does not vary from that of the octahedral arrangement, and it does not offer the space opportunity to revert to the rhombic form.

The long edges of the model are nearly of the same length, so that if the opposite sorts of zonal angles be brought together, the faces will nearly coincide, but yet be slightly divergent at the apical angles. If series be set alongside each other, there are about the divergent apical angles unfilled spaces to permit of rotation above, below, and laterally. In the vicinity of the divergent apical angles, are four zonal angles to which the apical angles would be powerfully attracted. The apical angles would differ widely from the zonal ones in electro condition, if the angles as in phosphorous have their electro quality according to the distance from the centre, and so be powerfully attracted to the shorter or zonal angles. The two atoms which would tend to rotate would have their zonal angles thrust apart. The zonal angles are very similar, and so would not have the same powerful attraction *inter se* as the apical angles have for their neighboring angles, and in addition to greater attraction of the apical angles, they have a very decided leverage over the zonal ones, and their attraction would prove effective.

Did this attraction not prove effective, continued form would be impossible under this arrangement.

This arrangement perpetuates the slant of the first series to the base, and the slant occurs in the direction of the small axes of the base, and the axes of the base are not only oblique to themselves but the short axis of the base is oblique to the columnar axis, and the long axis of the base is at right angles to the columnar axis. This arrangement might be called a diclinic arrangement, or, as it is classed, a monoclinic arrangement of a different sort from the first.

In the unrotated series of atoms the zonal edge is oblique to the lines of series, thus ; in rotation it becomes less oblique and the series is thickened.

To estimate this widening, a model triangular face of sides 12.28, 20.387 and 21.177 inches respectively was made.

The triangle was then placed upon a sheet of paper and the outline marked. The triangle was then reversed, so that the zonal edge and the opposite sorts of angles are in apposition. A pin was passed through the cardboard at the centre of the zonal or short edge, and the triangle rotated through the divergence of the apical angles, and the position of the two zonal angles marked. One of the long sides of the triangle is produced both ways. A line is dropped from the angle apical to this line, and at right angles to it. This line represents the thickness of the single layer in its ordinary position. The distance of the new points brought about by rotation are measured from this line, and the sum of these measurements is the thickness of the rotated series. The lengths of these two lines are inversely according to the specific gravities of their arrangements. The line dropped from the zonal angle at right angles to the opposite and produced line, was $11\frac{1}{2}$ inches, and after rotation the combined distance of the zonal angles from this line is $12\frac{1}{16}$ inches. The correction of the divergence caused a thickening of $\frac{9}{16}$ of an inch, or $\frac{9}{16} \div 11\frac{1}{2} = \frac{1}{20.3}$ of the entire thickness of the series. $\frac{1}{20.3}$ more space is filled than in the divergent arrangement, for then the zonal planes are as in the octahedral arrangement, and the divergent portions are in the unfilled space.

In this arrangement six solid angles meet about a point in such a way that the two apical angles are not diametrically opposite but in apposition, while the other four are arranged as in the octahedral arrangement, with the similar angles diametrically opposite. The apical angles are free to move in space both up and down, and laterally. If they diverge until the long axes of the models are parallel, the arrangement then becomes octahedral.

Thus the primal form assumed accounts for, 1st, a gross octahedral arrangement of axes 1, 1.23 and 2.344;

2nd, a gross so-called monoclinic (really diclinic) arrangement of a base oblique to its columnar axis;

3rd, a condition of strain in the diclinic arrangement due to slight divergence of the solid zonal angles, the satisfaction of which strain sets free energy as heat;

4th, a rotation of the primal form in the diclinic arrangement in such a way that the series is thickened $\frac{1}{20.3}$ more than in the octahedral series, and that this approximates inversely the increase in space, as shown by the specific gravities observed in the two modifications of sulphur, thus, $\frac{20.5 - 19.6}{19.6} = \frac{1}{21.8}$;

5th, free spaces through which the divergent apical angles may converge, and through which they may rotate above and below, to assume the octahedral form, and *vice versa*;

6th, that the diclinic modification is in t zonal grouping like the octahedral arrangement, and rotation need occur in but one and an easy way, to assume the octahedral form.

Mr. Joseph Easton drew my attention to a most significant fact, viz., that in the molecular groups of the gas, the atoms are in the same proportions as they are in the smallest groups which give the complete outlines of the two crystal modifications of sulphur. The relationship goes even farther, and it is seen that the six-atom group, or octahedral group, is lower in temperature, both as a gas and solid, than the two-atom or diclinic group.

There are three modifications of selenium as of sulphur. These may be compared as follows :—

SULPHUR.	SELENIUM.
Amorphous, spec. gr. 1.92. Von Buchka.	Amorphous, spec. gr. 4.28 to 4.3. Von Buchka.
Diclinic or (monoclinic), spec. gr. 1.96. Von Buchka.	Monoclinic, spec. gr. 4.5. Von Buchka.

These monoclinic forms are said by Richter to be isomorphous.

Rhombic octahedra :

Spec. gr. 2.06, Von. Buchka.

“ 2.05, Richter.

“ 1.9-2.1, Zirkel.

The most stable form, to which the de- or monoclinic form slowly reverts at ordinary temperatures, with the evolution of a small amount of heat.

Rise of the spec. gr. in transition from 1.96 to 2.05 = $\frac{1}{20.5}$

Gray metallic lustre of form unknown :

Spec. gr. 4.8, Von Buchka.

“ 4.8, Richter.

The most stable and insoluble modification to which the monoclinic form, if heated to 97°C., reverts rising rapidly to over 200°C. in the transition.

Rise of spec. gr. in transition from 4.46 to 4.8. Von Buchka.

$$\frac{3.4}{4.80} = \frac{1}{1.4}$$

From 4.3 to 4.8. Richter.

$$\frac{5}{4.8} = \frac{10}{9.6}$$

The difference between the two crystal forms of sulphur is less, and the change easier, than between the two crystal forms of selenium, that is there must be a wider difference between the zonal axes.

If selenium be isomorphous with sulphur, it follows that an absolute coincidence of form is not necessary to isomorphism. That both sulphur and selenium occur in forms which are under a strain, and have a mobility within their arrangement, is in itself an enunciation of the principle of possible non-apposition of the axes, and unstable equilibrium.

Tellurium is found in both hexagonal and rhombohedral forms.

Von Buchka hexagonal.

Richter rhombohedral.

Zirkel { rhombohedral, by Rose.
..... hexagonal, by Rose.

Dana hexagonal.

In rhombohedral forms according to Rose the angle $R = 86^\circ 57'$, and in the hexagonal form with "mit pole Kante of $R\ 71.54$." The angle $86^\circ 57'$ is very much akin to angle of bismuth $87^\circ 40'$, and could intercrystallize with bismuth. The angle $71^\circ 54'$ is very much like the angle $70^\circ 31' 47''$ of the regular tetrahedron, and is really the complement of the angle of the regular octahedron. If regular octahedra be placed face to face, their outlying points are in a hexagonal series, and are capable of a rhombohedral series of angles $R\ 82^\circ 18'$, or of in the hexagonal system $70^\circ 31' 47''$. Close observation of numbers of crystals may show these angles. As a coincidence supporting a view of the atom of tellurium approximating the regular octahedral form, may be quoted the fact of its isomorphism with gold, which is distinctly regular in form.

There remain undiscussed in this group chromium, molybdenum, tungsten and uranium.

Of chromium alone the crystal form is known, and that with no certainty. Von Buchka says it occurs in "mikroskopische fast zinnweisse rhomboh eder, oder quadratische Pyramiden." Remsen says "in lustrous rhombohedra of tin-white color."

Were the chromium atoms joined face to face, they would have three areas of valence unsupplied, and the chemical valence would be three, with the result of formula $Cr_2 Cl_6$ and $Cr_2 O_3$. There are unstable compounds, chromium dechloride and chromium bi-hydroxide. From the hydroxide an oxide of the formula $Cr_2 O_3$ is obtained, and not one of the formula $Cr O$.

The valence of molybdenum, tungsten and uranium will be studied later.

A question arises as to why sulphur, which has four angles of valence near its centre, and so four electro-negative areas of valence, should form a dihydride instead of a tetrahydride.

Facts furnished in the study of chlorine and the chlorides, show that if one angle of valence be satisfied, the diametrically opposite angle is to a greater or less extent satisfied. This question is fully discussed in connection with chlorine.

CHAPTER V.

The Atom Form of Iodine and the Phenomena of Crystallization of Iodine From Solutions.

In group VII. of Mendeljeff's table there are five elements to study, fluorine, chlorine, bromine, iodine and manganese. Of these elements fluorine and chlorine are gases at ordinary temperatures, and bromine a liquid, so that their crystal forms are impracticable for present study.

Iodine occurs as a distinctly crystalline solid at ordinary temperatures. From the molten state it is found to solidify in distinctly foliated plates and leaflets.

Cleavage is shown in one direction, and in this direction there must be a special regularity of arrangement. The cleavage shows ease of fission, that is less tenacity in the plane of fission, and hence less attraction.

This plane is very smooth and glistening, that is there is no roughness of the plane or perceptible intrusion, or in other words there is a continuous arrangement along the plane of fission. A group of atoms closely bound together and passing into both planes, would make fission more difficult, to the extent of the greater amount of energy required to dismember the group than the layer, or the increase of energy required to displace the group through a series of continuously arranged atoms, which have an inter attraction.

Upon the leaflets are often observed striations, and even raised minute ridges which meet each other at angles 36° , 72° , 108° and 144° . When these ridges are more developed they become developments in the third dimension. This circumstance is of interest in further study. It has been noticed that the rhombic plates have an easy and natural fission in planes parallel to the surface of the plate. These plates are, however, flexible and show considerable tenacity in the two dimensions in which the leaflet lies. Fission, when forced, tends toward assuming lines at 36° , 72° , 108° and 144° to each other, but is indistinct and is most frequently irregular. This indicates a greater attraction in this plane, a continued arrangement to produce plate forms of angles 36° , 72° , etc., and that there are other lines of fission, and that the lines of fission pass through the series which cause the grouping in angles 36° and 72° .

The striae arranged one behind the other would show rows or series of rows as mentioned by Hany.

Iodine is soluble in ether and in chloroform, and more soluble in the former than in the latter. If a saturated solution of iodine in ether be slowly evaporated, the result is a casting down of rhombic octahedra, of roughly formed rhombic plates, the angles of which are represented by a meeting of octahedral faces P, and of a crystalline aggregate about the sides of the

evaporating disk, in which the crystals are elongated and striated, the striæ being at angles 72° , 36° , 108° and 144° to each other. From a saturated solution of chloroform, in which the evaporation is slower, there is a special tendency to the formation of octahedra. There are also needle-shaped crystal forms, which grow, by addition from the evaporating solution, to rods with octahedral ends. These crystals are too small for measurement with a contact goniometer, and so were measured under 125 D enlargement, the arms of the goniometer being placed parallel to the edge of the image, as seen through the microscope.

To place the crystals a cardboard was roughened, and the crystal laid in the fuzz, and so moved that the outer edges are in the same focus, or by cutting a slit in a piece of cardboard into which the crystal is placed, and may be made to show its edges in the same focus. In placing the crystals, a graphite pencil point was used, in that it was not corroded as a metal point would be.

The measurements taken were of the angles which like edges make upon each other.

The same crystal was measured upon both sets of edges :

1st		< A B C	72°		< E B D	$= 54^\circ$;
2nd		< "	72°		< "	$= 54^\circ$;
3rd		< "	72°		< "	$= 54^\circ$;
4th		< "	72°		< "	$= 54^\circ$;
5th		< "	72°		< "	$= 54^\circ$;
6th		< "	72°		< "	$= 54^\circ$;
7th			$\begin{cases} 72^\circ \\ 72^\circ \end{cases}$		$\begin{cases} < E B A = 27^\circ \\ < E B F = 54^\circ \end{cases}$	$< F D \text{ on } EB = 27^\circ$;

Of the first six the regularity is very striking, and specially so since they are from different batches of crystals. Number 7 gives two series of measurements, one at each end. The angle 72° is constant, and is in the broader plane of the crystal. At the one end, the 27° is that part between the outer edge, and the line which bisects the angle between the usual sides of 54° , or the angle between the outer edge and the edge, which were the crystal rotated 90° would form an outer edge. This crystal was a little point by itself; the main point was at 54° . The other end of the crystal shows over its point an angle of 54° .

From one of its sides goes another line which lies at 27° to the opposite edge. The angle of 54° has a line bisecting it, and the new line or edge is parallel to this bisecting line or edge.

If a saturated solution of iodine in ether be placed upon a glass slide under a microscope of D 125, and be permitted to evaporate slowly, the result will be a multitude of octahedra.

These are thrown down as soon as evaporation commences, and the octahedra are drawn towards that part at which there is most fluid.

A rapid evaporation leads to octahedra, to needle forms with octahedral points, to a series of parallel needles, which may be united by bars to give a coarse retiform form.

In saturated chloroform solutions of iodine, slowly evaporated, are seen more perfect octahedra, and more perfect rhombic plates. These plates show a selection of obtuse for acute angles and *vice versa*, and one may see formed from two, three, or four smaller plates, a complete oblong plate, an incomplete one of three, thus , or even a complete plate by four, thus .

Evaporation is slowest in chloroform, hence the more perfect octahedra.

Diagonally across the plate between the two angles of 72° , is seen a line, thus .

If the iodine be permitted to volatilize, the edges and this median line remain, till towards the end. The portion between them is most frequently the first to assume vapor form. The edges of all crystals of the iodine, show by refracted light, a violet fringe of color similar to that of the vapor, or the chloroform solution.

A rapid evaporation of the solvent, gives a series of small plates, small octahedra, a series of coarse needles, and sometimes a very beautiful series of fine needles, or a fine retiform conformation which, under 450D, still appears very fine. The outline of such a retiform mass, is roughly rhombic. Iodine is a volatile element, and as a result of the immense exposed surface in a retiform arrangement, the evaporation is very rapid. If a retiform crystal be allowed to evaporate on a slide, under a microscope of D 450, one little bar disappears, and then another, till some outlying portion would tend to be isolated. Were there no attraction, the isolated portion would remain where it was deposited. This is not the case. The minute particles, so soon as they are not held off by intervening solid particles, immediately spring, with great rapidity, to the nearest portion of the crystal, showing a very active attraction.

In the slow evaporation of a concentrated solution of iodine in chloroform, the crystal is seen to grow at the expense of the color within the solution. The color keeps going faster, and faster, till suddenly the color disappears, and the iodine has all been drawn to the crystal, even while there yet remains some of the solvent about a crystal.

This phenomenon shows an attraction of the crystal of iodine, for the iodine in solution. If there can be an attraction of the crystal of iodine for the iodine in solution, and the iodine still remains in solution, it follows that there is some counter attraction of the solvent for the iodine, and the solution is dependent upon this attraction. Thus solutions are a series of equasions of forces of attraction, and the effect of a crystal in a saturated solution is felt throughout the entire solution, as will be seen later.

It is in a moderately strong solution that the most may be observed. One easy of observation is made by adding to 1CC of saturated iodine solution, in ether, 2CC of ether and ethyl alcohol in equal parts. The alcohol is slower of evaporation, and lengthens the process of crystal formation.

When a drop of such solution is placed on a slide under a microscope, a brown solution is observed. In the field will probably be seen some small particles of dust, such as epithelium scales, cellulose fibre, etc., which have escaped one's slide cleaner. From one of these foreign bodies is seen a small needle to suddenly shoot forth, projecting itself out into the colored solution, and drawing the color from the immediate vicinity. The longer it proceeds the less is its rate of projection, and one may see its growth distinctly. It does not spring immediately into existence, but is an action of very perceptible duration. These needles project themselves towards the area in which there is the most color. The result is, that small needles come within the influence of others. If two be projecting themselves toward the same point, and nearly in the same line, when they approach, they cease their self-projection and proceed to draw the iodine from solution, and thicken themselves, showing instead of an attraction a repulsion the one of the other, even though there be a sufficient supply of iodine to permit of a growth to effect a junction. If, however, the point of a needle formed crystal approach the centre of another needle, and there be still iodine in solution, the point will project itself until it touches the centre of the needle.

If the approaching needle be free, or if it be of a later growth, it will attach itself at angles 36° or 72° . Sometimes a needle may be observed to take a curved course, and to arrive at the centre of another needle. This needle remains in the curved condition, until the iodine is absorbed from the solvent, and but a small amount of the solvent present; when, however, the solvent is gone, it suddenly straightens itself, freeing either the one end or the other of the curved crystal. The fact that the needles forming in the neighborhood of a larger and older needle crystal are at definite angles, shows an influence on the part of the larger crystal, over the solution in which the crystal was formed.

This will be discussed later, in connection with more direct evidence.

So far the conditions dealt with have been of immobile crystals. There are some interesting phenomena shown by mobile crystals. From a solution described as of moderate saturation, both mobile and immobile crystals are cast down. The fixed ones show the result of laws of attraction acting while they were becoming fixed. The mobile ones are amenable to the various attractions, acting upon it, and occupy such a position as is determined by the present attractions. The crystals are principally of rhombic plates and needle forms. If a mobile rhombic plate comes in the vicinity of another rhombic plate, its obtuse angle is seen to seek the acute angle of the station-

ary rhombic plate, and the sides to come quickly into apposition, or the crystal is sometimes seen to remain in equilibrium upon the other, thus 

If a current draw a small and mobile plate towards a large and immobile crystal, in such a way that the small one is borne down with its acute angle towards the acute angle of the stationary one, the mobile one will either rotate as it comes near the angle of the stationary one, or be apparently cast aside, and pass down the stationary crystal till the obtuse angle of the mobile crystal is in the neighborhood of the acute angle of the stationary one, and approximate their sides.

If a rhombic plate come in the vicinity of a needle formed crystal, the result is most frequently, that the rhombic plate seeks the octahedral end of the needle, towards which it acts as though the end of the needle were the acute angle of a rhombic plate. It may arrange its side parallel to that of the needle, or may arrange itself with its long axis parallel to long axis of the needle, or a series may so arrange themselves as to make the points, if joined, give a rhombic outline. Such an arrangement shows an attraction about, and at some distance from the needle, and that the area of attraction is present, whether filled or not, so long as there is an elongation of the crystalline substance in one axis, and that the area of attraction is in proportion to the elongation.

If a current of the solution bear a needle crystal towards the fixed crystal, so that the point of the one approach the point of the other, the point will rotate, and the side or centre of the moving crystal then comes in the vicinity of the fixed one. The needle will be attracted very rapidly, and will be held at an angle to the point of the fixed crystal. The centre of the needle has a very strong attraction for the point of another needle crystal, and there is apparently a similar attraction of the long to the short points, as in the atoms, as these points act not unlike the positive and negative poles of a magnet. If these positions be, as in the atoms, electro-negative and electro-positive, and the electro condition be dependent on length, then a shorter crystal placed by the side of a longer one, would, if their centres be together, be electro-positive to the longer one, and each part would be of a different electro condition to that at its side. The form would be determined by the proportions of the atoms, and a reason found for the subtraction of series.

In a saturated solution about a crystal that is growing may be observed currents from point to point. This may be due to some peculiar capillary action. Whether it be so, or whether it be due to an action of differently electrified molecules, brought about by different conditions at the different poles, it gives an opportunity of an equilibrium of supply.

In the field, between two needles, was seen a particle of something oscillating with great rapidity. A first supposition was that it was a very

small crystal, for the rapidity of its motion made it impossible to see what it was. The oscillation occurred between the point of one needle and the body of another. It at last became temporarily attracted to one of the needles, and was then seen to be an epithelium scale. There is an analogy between such an oscillation and that of an insulated pithball a + and a - static electrical poles.

If a dilute solution of iodine in ether and alcohol be evaporated upon a glass slide, under 125 D enlargement, the result will be as the last of the solvent is evaporating, very fine needles will be deposited, and do not float, but are cast down in the position dictated by the conditions in the solution at the time of their formation. These crystals, if in apposition, are almost invariably at angles of 36° and 72° .

In those which are not at angles 36° and 72° , there is some larger needle, and a prior one, which predominates the attraction of the other needle. This predominant needle will have its attachment to the needle, varying from the common angle. Such a regularity of position shows the influence of the needle over the iodine in solution.

The needles occur when the supply of the solution is little and the evaporation is hurried; the octahedra in the presence of much solution and those in which evaporation is slow; the one under the conditions in which selection is imperfect, the other where the selection is more possible; or the one an imperfect partially finished form and the other in a complete form.

The physical properties of iodine, for which a primal form must account, may be recapitulated as, 1st, a continued or crystalline structure; 2nd, easy fission in one series of planes; 3rd, more tenacity in the other two planes; 4th, grouping and a tendency to fission in lines of 36° and 72° to each other; 5th, grouping to give over the other edges of the octahedron an angle 54° .

In groups IV., V. and VI. of Mendeljeff's table, it has been found that the forms which have the same number of solid angles as the elements have areas of valence, account not only for its crystal form, but by different arrangements for the various crystalline modifications known of these elements, and the space occupied per atom form, corresponds inversely with the specific gravity of these modifications.

In group VII. the valence is seven, and if iodine be, as the other atoms of a form, of the same number of solid angles as the atom has areas of valence, it must be of one solid angled form.

In groups V. and VI. two of these angles are apical and the remainder zonal. If such a division of zonal and apical angles were the case in iodine, the result would, if the zonal angles were at regular intervals, be a regular pentagonal zone.

This form, *per se*, is not a rhombic form; but if in combination with another such form edge to edge and the zones in the same plane, the outlying edges, if produced, give a rhombic outline.

The angle of a regular pentagon is 108° and its supplement is 72° , so that the above grouping gives the required angles of one of the planes of iodine. In such an arrangement, two zonal angles of an atom meet two zonal angles of a contiguous atom, while if a layer be placed over another layer, they meet by single apical angles. The atoms are more attached in the zonal plane than by the apical solid angles, and hence the tenacity in the zonal plane, and the ease of fission of the apical plane of attachments.

The grouping of the atoms with their two zonal angles together, is in the proportion of the grouping in the gaseous molecule, and is an interesting one when compared with sulphur.

As yet but a group of two atoms has been discussed. It is evident that these double atom groups must themselves be arranged.

This may be done in two ways:

1st, as in fig. I., in which the atoms are (except within the group) attached by one point only;

2nd, as in fig. II., in which the atoms are attached to each other by two angles.

The first case may be disposed of in that the lines of fission are at right angles and demand a right angled form. Such a form does not occur in iodine. In such an arrangement the atoms are attached by one point as are the apical angles, and so do not tend toward tenacity.

In fig. II. the series are not at right angles, and about the most outlying angle of the double atom group are attached two other angles. In this arrangement in the zonal plane each atom is bound to three other atoms by two areas of attraction, and to two other atoms by one area of attraction.

The series of outlying points may be shown to be at 36° to each other. About the point A are three angles of 108° , or in all 324° . All the angles about A = 360° , therefore the angle E A B = $360^\circ - 324^\circ = 36^\circ$. The angle A E F = the angle E F G, therefore A E is parallel to F G. Similarly A B may be shown parallel to C D. Therefore F G and C D are at an angle of 36° to each other, and these lines being parallel to the outlying angles, the outlying portions of the series are at an angle of 36° .

In fig. III. two possible arrangements are seen about the double atom group B F H C.

If arranged as C H Q P, the arrangement is merely another series added to a grouping, as in fig. II., and the series arising from this arrangement are at angles of 36° . If it be arranged as the double atom group D S N R, there are two different sets of series lying together, each of which has its internal series at 36° . Thus E H is parallel to G J, D F is parallel to G K, and G J is at 36° to G K, therefore E H is at 36° to D F. D F is at 36°

to D L, therefore D L is at $2 \times 36^\circ$ or 72° to E H, and D L is parallel to M N, therefore M N is at 72° to E H, and these two lines are parallel to the outlying angles of the different series, so that the outlying edges of a crystal of this arrangement are at 72° . The line of union of the series runs diagonally across the rhombic plate between the two angles of 72° . The arrangement above described accounts for the proportions and physical properties of the rhombic form of iodine in its plane of tenacity.

The properties in the third dimension are accounted for as to its fission. If the second layer of atoms be attached, one row within the first layer, the angle in this dimension at the corner of the rhombic plate will depend on the line from the apex of the corner atom of the one layer to apex of the atom upon which rests the corner atom of the second layer, and the thickness of the corner atom of the second layer.

This angle is one-half that over two opposite edges of an octahedra, and is dependent on the thickness of the atom. If the atom be of a thickness equal to its zonal edge, this angle may be shown to be 27° , or the whole angle over the octahedral point is 54° . The crystal of iodine has these proportions. This is a coincidence rather than a necessary portion of the hypothesis of the bipyramidal decahedral form for iodine.

This form has two angles near the centre, so that one would expect the hydride of its analogous element chlorine to be of the formula $H_2 Cl$. The hydride of chlorine is a mono-hydride. Chlorine acts as a bivalent element towards potassium and silver. This shows there to be two electro-negative valences in chlorine, and that if one be satisfied by hydrogen, the diametrically opposite valence is satisfied. In phosphorous the zonal angles are not opposite, and differ in their manner of satisfaction of the areas of valence by hydrogen. Suppose this peculiar action on opposite angles of valence occur in sulphur. There are two sets of opposite short axes, and so require two atoms of hydrogen per atom of sulphur, and the sulphide would then be a dihydride. This is the hydride which actually does occur.

Manganese has a valence of seven in potassium permanganate. Its crystal form is however unknown.

There is a series of elements, the grouping of which according to their valences, would make their places in Mendeljeff's table uncertain, were it not for their atomic weights.

Nickel	2, 4, 8
Iron	2, 4, 6
Chromium	2, 6
Molybdenum	2, 4, 5, 6 and 8
Uranium	(2, 3), 4, 5, 6, 8
Osmium	2, 4, 6, 8
Iridium	2, 4, 6, 8

Molybdenum is classified in the group with sulphur. It has an oxychloride and an oxide of formulae MOCl_4 , and MO_3 . These compounds show a hexavalence. There is a sulphide, molybdenum tetrasulphide.

If molybdenum be of a form similar to sulphur, the zonal angle of the sulphur may be in apposition to the apical angle of the molybdenum, and the apical angle of the sulphur atom, in apposition with the zonal angle of the molybdenum atom. This may occur at both ends in such a way as to be balanced and give attachment to the opposite angles of the sulphur atom. This arrangement leaves two diametrically opposite angles of the sulphur atom unsupplied, to which might be added two sulphur atoms. Were these atoms of sulphur added, it would give the tetrasulphide, and sulphur would act monovalently. If sulphur be of a form like molybdenum, then by analogy one would expect sulphur dioxide to have this balanced arrangement. In formation sulphur dioxide gives heat. The action represented by the equation $(2\text{SO}_2 + \text{O}_2 + 2\text{H}_2\text{O} = 2\text{H}_2\text{SO}_4)$ gives more heat. The heat given by the action represented in the equation $(2\text{SO}_3 + 2\text{H}_2\text{O} = 2\text{H}_2\text{SO}_4)$ is less than that represented by the equation $(2\text{SO}_2 + 2\text{H}_2\text{O} + \text{O}_2 = 2\text{H}_2\text{SO}_4)$, so there must be heat given in the action represented by the equation $(2\text{SO}_2 + \text{O}_2 = \text{SO}_3)$.

To bring about the further oxidation of sulphur dioxide, some agitation such as heat, or the presence of a very powerful strain as water and nascent oxygen together, is necessary. That is, the arrangement of the sulphur dioxide must be changed before further oxidation can take place. To account for sulphur trioxide, an oxygen atom must occupy an apical and a zonal angle of sulphur. This occurs at both ends, and so there remains two zonal angles as yet unsupplied. If one atom supply both valences then the unoccupied points must be contiguous. This is the condition as rearranged, therefore the alternative condition is that in which the diametrically opposite zonal angles are occupied.

It is not improbable that there is an intermediate form like that of the molybdenum.

Group VIII. of Mendeljeff's Table.

Group VIII. consists of three distinct series, each series being of about the same atomic weight. The first series, iron, nickel and cobalt, have chlorides of the general formula X_2Cl_6 , each atom being bound by one valence to the other, and so is quadrivalent, and as such would be tetrahedral in atomic form. Iron and nickel occur in regular octahedra. Cobalt is isomorphous with both iron and nickel, but its form, *per se*, has not been determined.

The second series, ruthenium, rhodium and palladium, have chlorides similar to those of the first series. The crystal form of ruthenium and rhodium are unknown. Palladium occurs in regular octahedra.

The third series consists of osmium, iridium and platinum. Osmium has chlorides of the formulæ Os Cl_2 , $\text{Os}_2 \text{Cl}_6$ and Os Cl_4 , and oxides of the formulæ Os O , $\text{Os}_2 \text{O}_3$, Os O_2 and Os O_4 . With the exception of osmium tetroxide the oxides and chlorides correspond in valence, assuming the valence of chlorine one and oxygen two. If oxygen act monovalently, as does its analogue sulphur in molybdenum tetrasulphide, then the osmium tetroxide would show a tetravalence as it does in its highest chloride. The same may be said for the oxides and chlorides of iridium.

Platinum has chlorides of the formulæ Pt Cl_2 and Pt Cl_4 , and oxides of the formulæ Pt O and Pt O_2 .

The crystal form of platinum is of regular octahedra and cubes. Thus group VIII. shows, with the exception of iridium and osmium in their tetroxides, a quadrivalence and the tetroxides may depend on a monovalent action of oxygen.

CHAPTER VI.

The Atom Forms of the Elements of Group III., II. and I. of Mendeljeff's Table.

The elements of group III. have three apparently equal valences. If these be equal in quality they will, if like the atoms discussed, be equal in position. Three points arranged equally about a centre, lie in a plane, and if joined give rise to an equilateral triangle. The elements of this group, of which information as to the crystal form may be obtained, are boron, aluminium, gallium. Of thallium we know that it is a very soft malleable metal.

Boron (see Richter's Chem. Eng. Trans., p. 244) crystallizes from aluminium, showing transparent, more or less colored crystals of specific gravity 2.63. "The crystals are not pure but contain carbon and aluminium. In their lustre, refraction of light and hardness they resemble the diamond." Von Buchka records them as quadratic, or monoclinic, and Richter as quadratic. It is isomorphous to carbon, which is regular, and to aluminium. In the isomorphous conditions it has a refraction similar to the regular system. That the crystal is impure detracts greatly from the value of the observations upon it. That it is isomorphous with carbon is a most significant fact as to its form. It must then be able to take a place with carbon, in the formation of gross forms, and so is of a similar form.

If equilateral triangles be placed together, they may form a regular tetrahedron as the simplest solid form, and these together would form the arrangement to give octahedral form.

Aluminium occurs in octahedra (Von Buchka), but of what sort is not stated

Gallium is found sometimes in long, sometimes in short quadratic octahedra, and sometimes in oblique octahedra, thus showing a mobility of form. The variation of the quadratic forms to oblique ones, means a variation of the relative positions of the atoms, akin to that of graphite, sodium and potassium.

A series of triangles set edge to edge do not tend to each others support except as they are bound to each other. If the triangle have thickness, and the angles of the triangle be attracted, these angles might be in approximation, and yet have varying positions, as on one either side of the triangle. If two points of a triangle be fixed, it still has a power of rotation about these points. Thus if one point only be free, it is mobile in a circle.

From a tetrahedral form of atom, a less mobile form might be predicted. In tetrahedra any attraction to a free angle would displace another angle to move the atom, or it might even have to replace two, in other words would have to overcome the equilibrium of a tripod.

If there be attached about the angles of these triangular atoms, three of another sort of atoms, the result will be in outline an equilateral triangular plate. If these triangular bodies be placed layer above layer, they will give triangular columns, and if these be placed together, they give a hexagonal arrangement.

That such occurs in aluminium oxide, shows aluminium to be of an equilateral triangular form.

In group II. there are two somewhat different series of atoms, viz. :—

Beryllium, calcium, strontium, barium, and magnesium, zinc cadmium, and mercury.

Of the first series it is known that beryllium is hexagonal, and that the other elements are soft ductile metals.

Magnesium occurs as octahedra, but of what sort is not stated by Von Buchka.

Zinc occurs in hexagonal plates, and in pentagonal dodecahedra; cadmium occurs in regular octahedra; mercury occurs in regular octahedra.

The forms thus divide themselves between the hexagonal and regular systems, and zinc is capable of both. It is probable that all are capable of both forms, but have not been observed as yet.

The theory of the areas of valence representing the prominent portions of the atom, requires for this group two prominences, which, if joined, would have more or less of a rod form. An arrangement of these rods must account for a hexagonal and regular form.

The arrangement side by side would not give rise to a hexagonal arrangement, or a regular arrangement. Three might form a triangle, which would of necessity be equilateral, and which would, if placed angle to angle and in the same plane, give a hexagonal arrangement. The thickness of the rods

would give length to the hexagonal column. They might be attached, as are the lines of union in the diamond model, twelve about a point.

This would give the spaces between the atoms an equilateral triangle and the resultant gross form would be in regular octahedra. Such an arrangement involves a mobility and ease of arrangement of the atoms.

The elements of group I. have a valence of one and occupy space. The atoms of this group may be a sphere, in which all portions are of the same sort, or may be a sphere in which one portion only is attractive.

Hydrogen is of this group. Of it we know that it has at least two atoms per molecule. Were there but two, there would be a full satisfaction of the bonds of valence in the gas molecule. The coincidence of vapor sulphur in molecules of 6 and 2 as full groups of the forms giving rise to the two crystal modifications, and of iodine in groups of two, or the peculiar grouping in its crystalline form, shows a very close relation between the grouping in the gaseous and the solid conditions of the element.

While not conclusive evidence, yet it leads one to regard the molecule of hydrogen as existing not as of at least two atoms per molecule, but as (two atoms per molecule). The grouping of hydrogen gives rise to a rod form, which if rigid and in accurate and symmetric arrangement, would give rise to a regular or hexagonal form as in group II. They do not exist as rigid rod forms, but as forms with a joint in the middle, and so a new cause for mobility, and a new opportunity of variation and irregularity of form.

If the atoms be spheres of which all points are equally attractive, they would lie as shot in a pile, and would be of but one possible form, a regular form.

Copper, gold and silver occur in regular octahedra. Potassium and sodium occur in long and short octahedras and in cubes. They may be cut, moulded, drawn out, made to sag in any direction, are cut easily with a knife, and apparently have no choice of position. That they occur in cubes and in octahedra, shows that with their malleability, they have a choice of position, and a series of lines of crystal energy or differentiated attraction, and that their lack of resistance to moulding pressure is due to very free intermolecular mobility, and not to absence of definite lines of attraction. In annealed copper this tenacious condition exists, but in it there is more tendency to crystal form, and regularity in that form. In silver the crystalline characteristic is less marked, and it is more ductile and softer than copper. There is more mobility of the atoms *inter se*. These characteristics are more marked in gold than in silver.

There are compounds of the formulæ Ag Cl , $\text{Ag}_2 \text{Cl}$, Ag O , Cu O , $\text{Cu}_2 \text{O}$, $\text{Cu}_4 \text{O}$ and Au Cl , Au Cl_2 and Au Cl_3 .

Cuprous and cupric oxides are common, and the bivalence is well marked. As a result of more than one bond of valence, the position arising from these two areas of attraction is more stable than that which would arise from but one area of attraction.

This may be said of the other two elements, gold and silver.

In the American Journal of Science, June, 1889, p. 446, an article by Mr. Cary Lea, of Philadelphia, appeared, in which he demonstrates four forms of silver, three unstable, and one stable or the common gray silver.

The following is quoted from his description of the unstable modifications:—

“A. Soluble, deep red in solution, mat lilac blue or green, while moist brilliant bluish green, metallic when dry.”

“B. Insoluble, derived from A, dark reddish brown while moist, when dry resembles A.”

“C. Gold silver, dark brown while wet, when dry exactly resembling gold in burnished lumps: of this form is a copper colored variety insoluble in water, and with no corresponding soluble form.”

The steps necessary to build up regular formed bodies from spherical forms are, 1st, two spheres together to give a rod form; 2nd, two rods attach each other and a long clumsy rod results. The dimensions of this double rod might be a cause of the insolubility of modification B; 3rd, three rods to form a triangle; and 4th, the rods arranged in the places of the lines of union, of the edges of the tetrahedra in the diamond model, to give a regular and stable form. There is a coincidence between the four arrangements of a sphere form, and the four allotropic modifications of silver.

Malleability and softness have a coincidence with arrangements of form, to permit intermobility of atoms. The atoms of group I. of Mendeljeff's table are attached by one area of attraction, and so are less stable of position and more malleable. The atoms of group II. have high functions of atomic intermobility, for if one area of attraction be wrenched free, it may, unless hindered by some other atom, rotate in a sphere about the fixed area of attraction. They are of lower intermobility than those of group I., for their rod form is not jointed in the centre. In group III. there is a very free intermobility of the atoms permitted by form, though less than in group II., for if one area of attraction of the atom become free, it may, until stopped by some other atom, rotate in a circle, the centre of which is the middle of a line joining the other two areas of attraction.

In group IV. new conditions arise, from which may be determined some other factors, in producing softness and hardness of elements. The atoms of the elements of group IV. are tetrahedral in form, so that each angle or area of attraction is as the apex of a tripod to the other three areas of attraction, and so its position tends to be a most stable one. The tetrahedra are of two sorts, regular and quadratic. The regular is more compact, more simulating a sphere so that its rotation causes the least possible displacement. The quadratic tetrahedra are not so compact and simulate an ovoid figure, and so in rotation would cause considerable inter-atomic displacement. Tin is quadratic and in twisting or bending causes a crying sound, due to this

atomic displacement. Lead is of a regular form and does not emit this sound. Another factor of inter-atomic mobility is shown by the following comparison:—

Group I.	$\left\{ \begin{array}{l} \text{Copper} \\ \text{Silver} \\ \text{Gold} \end{array} \right\}$	Increasing malleability, with increasing atomic weight, and decreasing chemical activity.
Group II.	$\left\{ \begin{array}{l} \text{Magnesium} \\ \text{Zinc} \\ \text{Cadmium} \\ \text{Mercury} \end{array} \right\}$	Increasing in softness with increase of atomic weight, and decrease of chemical activity.
Group IV.	$\left\{ \begin{array}{l} \text{Diamond as regular tetrahedral primal form, brittle.} \\ \text{Tin malleable, breaking with crystalline structure.} \\ \text{Lead soft and malleable.} \end{array} \right\}$	
Group VIII.	$\left\{ \begin{array}{l} \text{Iron} \\ \text{Nickel} \\ \text{Cobalt} \end{array} \right\}$	<i>Per se</i> brittle as compared with platinum.

There is an increased malleability and ductility with increased atomic weight and decreased chemical activity.

There has been shown a coincidence of areas of valence, with those of crystal attraction, and that the quality of valence, as instanced in phosphorus, is a function of its position within the elements.

If carbon dioxide set free more energy than lead dioxide, the inference is that carbon has a more powerful chemical attraction for oxygen than lead has ; and if the supposition that chemical and crystal energies are different manifestations of the same energy, be correct, then the attraction of the carbon atoms *inter se* is greater than that of the lead atoms *inter se*. Thus the carbon atoms are held more firmly in position, and as carbon atom in the outer layer is attached to the crystalline mass in the diamond, with greater fixedness than a lead atom on the outside of its crystalline mass. If a diamond be broken the particles are in perfect adherence to the different masses, and so for a coaptation they would need to be brought into absolute apposition, for the atoms would not be movable, except under extreme pressure.

Were the atoms movable, then the prominences would spread themselves out under pressure, and a general apposition of the attractive areas come about. The adhesive power of graphite is an admirable example of easy coaptation, for the atom in its loose arrangement and its requiring merely points in coaptation gives a free opportunity of motion, and the coaptation demanded is easy of satisfaction.

The malleable character of an element may be attributed to ease of inter-atomic mobility, and this it has been seen is dependent on form and its

arrangement, so that its displacement is but slight in movement, and also to ease of inter-atomic mobility, due to weak inter-atomic attraction.

It is probable that we will, at no distant day, be able to determine the causes of the different physical properties of different sorts of matter, and of these causes form of atoms and molecules will bear no insignificant part.

In closing I cannot but express my sense of special gratitude to my friends Drs. Smale and D. H. McLaren, and Messrs. Hunter and Easton, for their assistance and kindly encouragement, under difficulties which they best appreciate.

WILLIAM L. T. ADDISON.

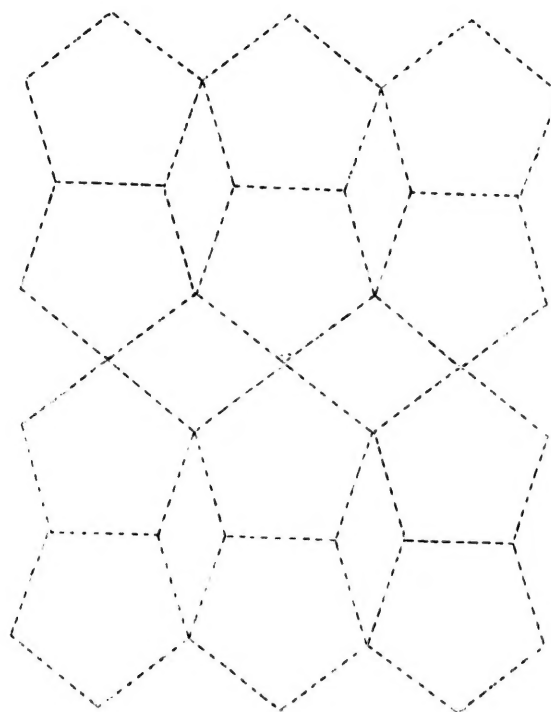


Figure I.



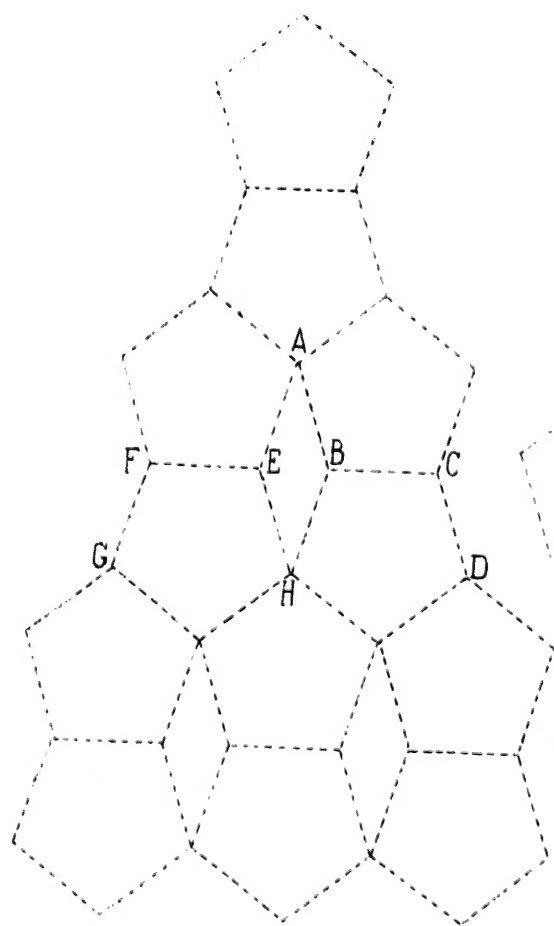


Figure II.

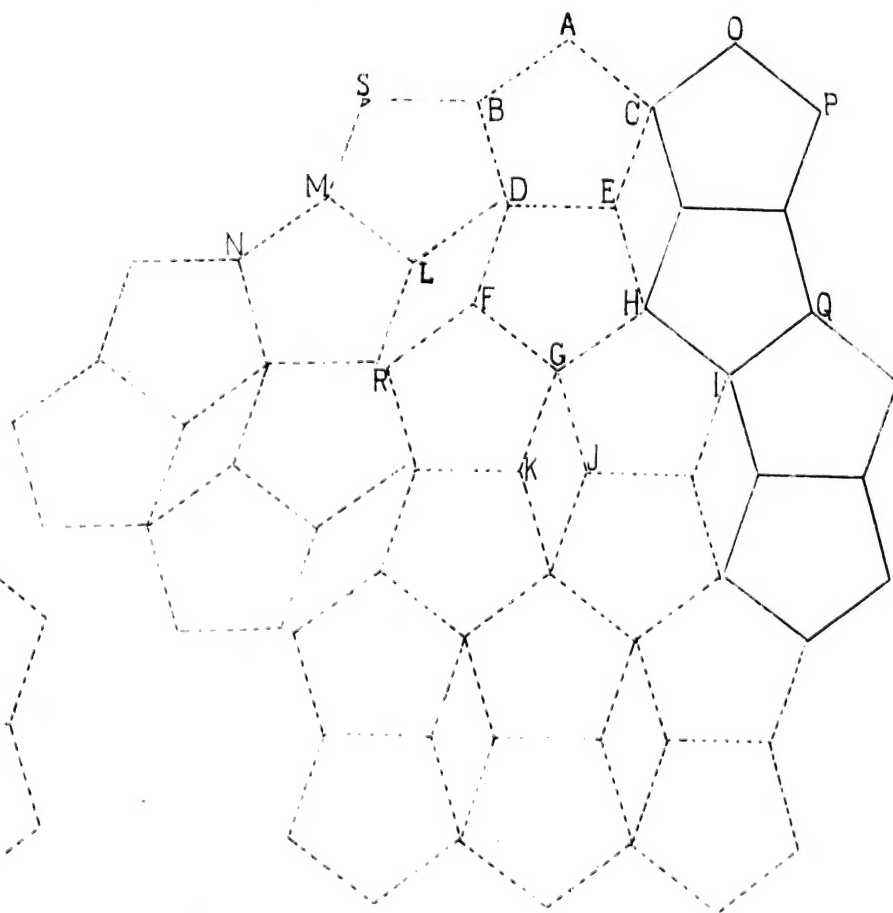


Figure III.